Imaging the Intervertebral Disk
Age-Related Changes, Herniations, and Radicular Pain

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KEYWORDS
- Intervertebral disk • Disk herniation • Degeneration • End plate

KEY POINTS
- Radicular pain requires both compression of neural tissue and an inflammatory response.
- Standard imaging can only detect nerve root displacement or compression; this is in part the basis of the specificity fault: many disk herniations are asymptomatic.
- The natural history of disk herniations is resolution; larger herniations, extrusions, and sequestrations are more likely to resolve.
- There is no relationship between the size, type, or change in disk herniations over time and patient outcomes.

INTRODUCTION
The articulations of the spinal motion segment, consisting of the intervertebral disk in the anterior column and the zygapophyseal joints in the posterior column, inevitably undergo age-related changes in response to a variety of insults, as described by Bogduk elsewhere in this issue. This article focuses on the intervertebral disk, specifically when fissures sufficiently weaken the posterior annulus so as to allow herniation of nuclear material into the outer annular lamellae as a contained protrusion or breach the annulus and pass into the epidural space as an extrusion. Such displaced nuclear material may directly impinge on neural tissue as well as initiate an inflammatory response in the epidural space, producing radicular pain and neural dysfunction. This article examines the imaging of age-related changes in the disc and the sequelae of internal disk disruption, disk herniation: appropriate nomenclature, the reliability and relative merits of imaging modalities, the imaging natural history of disk herniations, and most importantly, its clinical significance. The imaging professional cannot lose sight of the ultimate goal of imaging disk herniations: to improve the outcomes of patients with radicular pain syndromes and radiculopathy. The lumbar segment of the spine will receive primary attention.

The evaluation of disk herniations by imaging most frequently occurs in the setting of radicular pain or radiculopathy. Radiculopathy implies the presence of objective signs of neural dysfunction including motor weakness, sensory loss/paresthesias, or diminished deep tendon reflexes; it is typically accompanied by radiating limb pain which is described as intermittent, lancinating, electric, or burning. This pain differs from the referred pain from somatic sources, such as facet or sacroiliac (SI) joint...
inflammatory synovitis, which is characterized as constant, deep, dull, and aching. Radicular pain frequently extends into the distal limb, whereas somatic referred pain is seldom experienced below the knee or elbow. Lumbar somatic referred pain from facet or SI joints is often maximal after a period of immobility, arising from bed, prolonged standing or sitting, which eases with continued motion. Lumbar radicular pain may exist in isolation without objective evidence of radiculopathy; it is typically worse with axial load and upright posture and relieved by recumbency. Lumbar radicular pain may be accompanied by allodynia, pain provoked by light touch, but in general is not manifest in cutaneous innervation; it is best described as having a radicular, not dermatomal, distribution.

PATHOGENESIS OF RADICULAR PAIN DUE TO DISK HERNIATION

Mixter and Barr\(^1\) initially described the disk herniation as the cause of sciatica in 1934; this observation, and the ability to relieve pain and neurologic dysfunction by surgical extirpation of the offending herniation, provided the basis for the first 70 years of spine imaging. Myelography, computed tomography (CT), CT/myelography, and magnetic resonance (MR) imaging were deemed useful in patients with radicular pain or radiculopathy because of their ability to first indirectly, and later directly, visualize the disk herniation and neural compression. Over the past few decades, however, the pathogenesis of radicular pain/radiculopathy has been shown to be more complex. Muller and colleagues\(^2,3\) reviewed the evidence supporting an inflammatory component as essential in the cause for radicular pain. Clinical observations supporting the role of inflammation in radicular pain include\(^2,3\)

1. Surgical relief of neural compression is not uniformly clinically successful; pain may persist despite adequate decompression
2. Large disk herniations may be asymptomatic
3. The severity of symptoms has no relationship with herniation size or shape
4. Imaging features of herniation have little prognostic value
5. Conservative therapy is often effective

There is also experimental data to refute the exclusive role of mechanical compression and include an inflammatory factor in the generation of radicular pain.

1. The imaging natural history of disk herniation is resorption.\(^4\) Resorption is mediated by macrophage-produced metalloproteases and neovascularization.\(^5,6\)
2. The disk nucleus pulposis (NP) has been shown to be immunogenic (it is sequestered from the vascular space), and its presence can induce an inflammatory response mediated by phospholipase A2; Interleukins (IL) 1\(\alpha\), 1\(\beta\), and 6; tumor necrosis factor \(\alpha\) (TNF\(\alpha\)); and nitric oxide.\(^2\)
3. In a pig model, introduction of NP into the epidural space, without nerve compression, induced nerve dysfunction and histologic evidence of nerve fiber degeneration.\(^7\)
4. NP alone induces nerve dysfunction, but concomitant compression is necessary to cause pain.\(^2\)

There is also evidence, in animal and human models, that nerve compression alone is insufficient to cause radicular pain, hence there must be an associated inflammatory pain, hence there must be an associated inflammatory process. Kulish and colleagues\(^8\) performed disk resections on volunteers under local anesthesia; traction on a nerve not having contact with disk produced modest discomfort only, similar traction on a nerve contacting herniated disk reproduced radicular pain.\(^8\) Several investigators, in a series of animal experiments, demonstrated the following: NP applied to a spinal nerve induces nerve dysfunction; this dysfunction is reduced by anti-inflammatory agents; the dysfunction is due to substances secreted by NP cell membranes; TNF\(\alpha\) is the most likely agent although IL-1, interferon-\(\gamma\), and nitric oxide synthetase may contribute.\(^2\) A subsequent randomized controlled trial of the transforaminal epidural administration of etanercept (a TNF\(\alpha\) antagonist) in patients with lumbar radiculopathy yielded positive results.\(^9\) Hence radiculopathy and radicular pain are the product not only of nerve compression but also an inflammatory response, likely mediated at least in part by TNF\(\alpha\). Structural imaging studies can only view a necessary, but insufficient, component of the lesion generating radicular pain.

ANATOMY AND NOMENCLATURE OF AGE-RELATED CHANGES AT THE DISCOVERTEBRAL COMPLEX OF THE LUMBAR SPINE

The discovertebral complex is formed by the intervertebral disk and the adjacent cartilaginous vertebral end plate (Fig. 1). These components comprise a cartilaginous joint called an amphiarthrosis.\(^10\) The central nucleus pulposis is composed of 70% to 90% water; this is bound within proteoglycans.\(^10,11\) The proteoglycans constitute about 65% of the dry weight of the nucleus; collagen comprises 15% to 20%. The
proteoglycan units, including their bound water, together with the collagen, constitute the nuclear matrix.\textsuperscript{11} Chondrocytes are sparsely dispersed in the nucleus, primarily near the cartilaginous end plates and are responsible for proteoglycan and collagen synthesis. In infancy and childhood, the nuclear compartment makes up the vast majority of the volume of the disk; the annulus is small and discrete from it. As the disk ages, the boundary zone between nucleus and annulus becomes indistinct with progressive incorporation of nuclear volume into the annulus.

The healthy nucleus acts as a fluid, and applied axial load is dispersed radially, constrained by the fibrous annulus. The fibrous annulus comprises 60\% to 70\% water along with collagen and proteoglycans; collagen is dominant in the annulus.\textsuperscript{11} The annulus is organized as 10 to 20 concentric sheets (lamellae) of collagen fibers; each lamella has its fibers oriented at 65 to 70\degree from the longitudinal axis of the body. The orientation shifts its direction of angulation in alternating layers. Lamellae are often not complete circular layers but end with fusion to an adjacent lamella, which is most common in the posterolateral quadrant of the disk.\textsuperscript{11} The vertical ends of the lamellae in the outer annulus tightly bind it to the ring apophysis of the vertebrae. The collagen fibers of the inner annular lamellae are contiguous with the collagen of the cartilaginous end plate. The annulus serves to constrain the fluidlike nucleus, bulging slightly as it accepts radial load dispersed by the nucleus in response to axial-applied load. Axial load is transmitted to the subjacent end plate with slight temporal delay and attenuation of energy.

The cartilaginous end plate is 0.6 to 1.0 m thick, composed of hyaline and fibrocartilage; as the disk ages, the fibrocartilage dominates. The collagen fibers in this fibrocartilage are contiguous with those of the annulus, now oriented horizontally, enclosing the nuclear compartment in a complete capsule of collagen.\textsuperscript{11} The end plate is tightly bound to the disk, less firmly fixed to the underlying subchondral bone. The intimate contact of end plate with marrow is critical to nutrient diffusion into the cartilaginous end plate and nuclear matrix.

With aging, the number of viable chondrocytes in the nucleus diminishes; the synthesis rate and concentration of proteoglycans decreases and the proportion of collagen in the nucleus increases.\textsuperscript{11} The water binding capacity of the nucleus decreases; it becomes more fibrous and stiffer. The nucleus is less able to bear and disburse load, transferring load to the posterior annulus. If the annulus remains intact, the joint expresses this added load by increasing its surface area, and osteophytes develop. If the annulus fails, fissures develop across annular lamellae; these may ultimately reach the disk periphery. This process of internal disk disruption may cause axial pain, as described by Bogduk elsewhere in this issue. It also sets the stage for the expression of degraded nuclear material through these fissures as a disk herniation.

The manifestations of age-related changes of the disk on MR imaging, most commonly referred to as degenerative change, consist primarily of diminished T2 signal within the nuclear compartment. The boundary between nucleus and annulus becomes indistinct, and the normal band of T2 hypointensity at the equator of the disk, the intranuclear cleft, may no longer be apparent. Pfirrmann and colleagues\textsuperscript{12} analyzed 300 lumbar MR images in 60 patients with a mean age of 40 years, and proposed a 5-part grading system for lumbar disk degeneration using midsagittal T2-weighted imaging. Parameters were T2 signal in the nuclear compartment and disk space height; there was good to excellent interobserver and intraobserver agreement (Box 1, Fig. 2).\textsuperscript{12}

The nomenclature of age-related changes of the disk, pathologic degeneration, and disk herniation has historically been chaotic because varied conceptual constructs of disk change over time coexist in the literature, and varied specialties have adopted different terminology. Multiple spine imaging and surgical societies proposed a lexicon of nomenclature in 2001; it represents the best effort to date to provide a uniform basis for communication.\textsuperscript{13}

In this terminology, spondylosis deformans (Fig. 3) is used to encompass normal changes of aging, including loss to T2 signal and anterior and lateral osteophytes. As the annulus bears more
load due to nuclear matrix degradation, there are reactive changes, primarily osteophyte formation. Nathan described the presence of anterior and lateral osteophytes in all cadavers at the age of 40, whereas posterior osteophytes were present only in a minority of cadavers at the age of 80. These age-related changes are typically relatively uniform across the spine. Loss of disk space height, posterior osteophytes, radial annular fissures, and large amounts of nitrogen gas in the nuclear compartment are not features of normal aging, in this description.

Intervertebral osteochondrosis is the term applied to pathologic, although not necessarily symptomatic, disk changes. This includes posterior osteophyte formation, large amounts of nuclear gas, loss of disk space height, profound loss of normal T2 nuclear signal, end-plate erosive changes, and reactive marrow changes as initially described by Modic and colleagues in 1988.

Box 1
Grading of lumbar disk changes based on Pfirrmann classification

Grade I: Homogenous bright white disk structure and normal disk height.
Grade II: Inhomogeneous disk structure with or without horizontal bands.
Grade III: Inhomogeneous disk structure. The distinction between nucleus pulposus and annulus fibrosus is unclear and the disk height is normal or slightly decreases.
Grade IV: Low signal disk with indistinct interface between annulus fibrous and nucleus pulposus. Disk height is normal or moderately decreased.
Grade V: Disk is collapsed.

Fig. 2. (A–C) Spectrum of disk degeneration using the Pfirrmann classification. (A) demonstrates a slightly inhomogeneous disk with normal height corresponding to grade II change (long white arrow) at level L1-L2; and the L2-L3 disk shows intermediate signal intensity with slightly decreased height corresponding to grade III degeneration (short white arrow). The L4-L5 disk is inhomogeneous with loss of distinction between nucleus pulposus and annulus fibrous and moderately decreased height (squiggly arrow), corresponding to grade IV change. (B) Homogenous black, collapsed disks corresponding to degeneration grade V are present at T11-T12, T12-L1, L1-L2, and L5-S1 (arrows). (C) The L2-L3 level has a normal disk, grade I (long white arrow), the L3-L4 level shows a slightly inhomogeneous disk corresponding to disk degeneration of grade II (short white arrow), and the L4-L5 and L5-S1 levels show gray to black disks with moderate decrease in height corresponding degeneration grade IV (squiggly arrows).
This process, and its imaging findings, typically involves one or more individual disks and is not uniform throughout the lumbar spine.

MODIC END-PLATE CHANGES

Modic changes provide an insight into the physiologic and histologic changes occurring in the disk-end-plate complex in response to insults and altered load bearing as the nuclear matrix degrades. Modic type I changes are characterized by decreased signal intensity on T1-weighted sequences and increased signal intensity on T2-weighted sequences. Histologically, the subchondral marrow is infiltrated by fibrovascular tissue. Modic II changes are characterized by increased signal intensity on T1- and T2-weighted sequences; the histologic correlate is yellow or fatty marrow replacement. Type III changes are characterized by decreased signal intensity on T1- and T2-weighted images and histologically correspond to sclerosis Fig. 4.15

Several publications16–19 evaluated the prevalence, distribution, and natural history of changes in the end plate. The reported prevalence of Modic changes is variable, but type II changes are generally more common than Type I. Kuisma and associates16 identified a distribution of 30% of type I changes, 66% of type II changes, and 4% of type III changes among 228 middle-aged working men. Eighty percent of all Modic changes occurred at the L4-L5 or L5-S1 levels. The investigators suggested that Modic changes occurring at the L5-S1 level, Modic type I changes, and extensive expression of Modic changes are more closely associated with pain.16 Karchevsky and colleagues18 studied the morphology and the epidemiology of the reactive end-plate bone marrow changes. Of the 100 patients studied, 40.5% had type I changes, 57.3% had type II changes, and 2.1% had type III changes. The most affected segment was the anterior end plate of the L4-L5 level; there was a positive correlation with weight and male gender.18

In an additional study, Kuisma and colleagues17 followed 60 conservatively treated patients with sciatica between the ages of 23 and 76 to assess the dynamics of changes in the end plate. At baseline, the prevalence for all Modic changes was 23%; 10% showed mixed Modic type I and type II changes, whereas 90% showed Modic type II change. During the observational period of 3 years the investigators found that 14% of the 70 disks with Modic changes converted to another type, and the lesions that did not convert extended. The investigators found that 80% of the conversions occurred from type II to mixed type I/II or to type I changes. These investigators suggested that Modic type II changes are probably less stable than previously thought.17,20,21 Hutton and
colleagues assessed the dynamics of Modic changes by reviewing 2 MR images of 490 end plates in 49 subjects with an average time interval of 695 days. Of the end plates with Modic type I changes, 36% progressed to Modic type II, 8% to Modic type III, and 6% to Modic type 0 (normal). Of the 22 Modic type II changes on the baseline MR image, 4 converted to Modic I whereas the others remain unchanged. The data in literature are thus rather disparate. Modic type II change is most common and Modic type III change is quite rare. Earlier literature had suggested a typical progression from the more active inflammatory state of Modic type I to a more quiescent Modic type II state; this has been challenged more recently. The correlation of Modic change with axial back pain of disk origin (discogenic pain) is discussed by Aprill and Maus later in this issue.

**HIGH-INTENSITY ZONE (ANNULAR FISSURE)**

The high-intensity zone was described by Aprill and Bogduk as an imaging finding marking the presence of internal disk disruption and correlating strongly both with the presence of a grade 4
annular fissure on post-diskography CT and concordant pain reproduction at provocation diskography. The inflammatory nature of this finding is manifest in its T2 hyperintensity (similar to CSF) and gadolinium enhancement (Fig. 5). The literature support for its correlation with discogenic pain will be discussed in detail by Aprill and Maus elsewhere in this issue.

**DISK HERNIATION NOMENCLATURE**

When radial annular fissures accompany nuclear matrix degradation, the stage is set for disk herniation; mechanical compression of neural elements and an inflammatory response induced by TNFα and other mediators combine to produce radicular pain or radiculopathy. Imaging to date has primarily been directed toward detecting the displaced disk material and its relationship to neural elements. A combined task force of the North American Spine Society, the American Society of Spine Radiology, and the American Society of Neuroradiology established the consensus terminology describing disk herniation. Disk herniation is the over-arching term, defined as “a localized displacement of disc material beyond the limit of the intervertebral disc space. The disc material may be nucleus, cartilage, fragmented apophyseal bone, annular tissue, or any combination thereof.”

The classification divides the surface of the disk into 4 quadrants (Figs. 6–8, Table 1). A localized herniation is arbitrarily defined as involving less than 50% of the disk circumference; generalized disk displacement of more than 50% of the circumference is a bulging disk. A localized displacement of the disk of less than 25% of its circumference is a focal herniation; disk displacement between 25% and 50% is a broad-based herniation. The distinction between protrusion and extrusion (see Fig. 6; Fig. 9) is one of shape. In a protrusion the width

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**Fig. 5.** High-intensity zone (HIZ). (A) Sagittal T2-weighted image in a 44-year-old man with axial pain shows HIZ within posterior annulus of L3 disk. Note also disk degeneration at L4 and L5. (B) Axial T2-weighted image at L3 demonstrates the HIZ within the bulging L3 posterior annulus. (C) Axial T1-weighted image at L3 shows only the mild contour abnormality (bulge). (D) Post-gadolinium axial T1-weighted image reveals enhancement with in the HIZ consistent with vascularized granulation tissue. (E) Sagittal post-gadolinium T1 image also demonstrates the enhancement in the posterior annulus of L3. (From Maus T. Imaging the back pain patient. Phys Med Rehabil Clin N Am 2010;21(4):725–66; with permission.)
of the displaced disk material, in any plane, does not exceed the width of its base or the aperture through which the disk material had left its normal position. In an extrusion, the width of the displaced disk material exceeds its base or aperture in any plane. The presence of an extrusion shape suggests that there has been complete disruption of the outer annulus, and disk material has entered the epidural space. Sequestration is the term for loss of continuity of a disk fragment with the parent disk from which it arose. Displacement of disk material away from the parent disk is termed migration. Migration can occur caudally or cranially. A herniated disk can further be considerate contained or uncontained. A contained disk herniation is one in which the outer annulus fibrosis is intact, an uncontained herniation is when the annulus in completely disrupted. The shape definitions of protrusion and extrusion apply to this, but only by implication not direct observation. CT or MR imaging can only rarely directly establish containment, only post-CT diskography can make this distinction.

Description of displaced disk material (see Fig. 7) in the axial plane is defined by zones: the central zone, defined by the medial margins of the facets; the subarticular zone, extending from the medial facet margin to the medial pedicle margin; the foraminal zone, extending from the medial to lateral margins of the pedicle; and the extraforaminal zone, peripheral to the lateral pedicle margin. A right-sided focal disk herniation may therefore be described as right central, right subarticular, right foraminal, or right extraforaminal. Similarly, location in the sagittal plane (superior–inferior) is defined by levels in relationship to the vertebral end-plate and pedicle margins. Extending from superior to inferior, the designations include the disk level, suprapediculular level, pedicle level, infrapedicular level, and the subsequent disk level. Although an element of subjectivity remains inherent in any usable system of terminology, careful adherence to the above...
descriptors should allow a more coherent discussion of disk pathology.

IMAGING MODALITIES

As noted by Chou and colleagues earlier in this issue, imaging is not indicated in the initial presentation of a patient with radicular pain or radiculopathy. The American College of Radiology considers spine imaging appropriate only when there are red flag features that suggest the presence of an underlying systemic disease, in the face of progressive neurologic deficits, or cauda equina syndrome. The American Pain Society and American College of Physicians further emphasize that imaging should be recommended only when the patient with radiculopathy is a candidate for a therapeutic intervention, such as epidural steroid injection of surgery. There is no benefit from imaging in planning conservative therapy.

If the patient has failed clinically directed conservative therapy, it is reasonable to consider imaging. This should occur in the context of a risk-benefit assessment, with appropriate consideration of potential harms of imaging, as discussed by Chou and colleagues elsewhere in this issue. When imaging is performed on a patient with radiculopathy or radicular pain, the first step is to obtain radiographs in an upright physiologic position. The advantages of physiologic imaging are discussed earlier in this issue. Oblique or flexion-extension radiographs have no role in the initial evaluation of the patient. Radiographs serve to establish spine enumeration, coronal and sagittal balance, and

![Fig. 7. Schematic representation of the anatomic “zones” identified on axial images. The anterior zone (not illustrated) is delineated from the extraforaminal zone by an imaginary coronal line in the center of the vertebral body. (From Wiltse LL, Berger PE, McCulloch JA. A system for reporting the size and location of lesions of the spine. Spine 1997;22:1534–7; with permission.)](image)

In the axial image, the sagittal and parasagittal planes are called **zones**.

![Fig. 8. Schematic representation of the anatomic “levels” identified on cranio-caudal images. (From Wiltse LL, Berger PE, McCulloch JA. A system for reporting the size and location of lesions of the spine. Spine 1997;22:1534–7; with permission.)](image)

In the caudocranial direction visualized on sagittal and coronal images, we have chosen the term **levels**.
A low sensitivity screen for undiagnosed sinister conditions. The common age-related changes seen on radiographs are seldom clinically useful. Advanced imaging in the form of CT, CT myelography, or MR imaging may provide more useful information in patients with radiculopathy.

CT has undergone a revolution in the last decade with the advancement of multidetector technology. A dataset for the lumbar or cervical spine can be obtained in a few seconds, eliminating motion artifact and dramatically improving patient tolerance. This dataset can then be reconstructed in any plane without the loss of spatial resolution or additional radiation exposure. CT provides superior imaging of cortical and trabecular bone compared with MR imaging. CT also

Table 1
Classification of disk herniation

<table>
<thead>
<tr>
<th>Area of the Disk</th>
<th>Shape of the Disk</th>
<th>Axial Location</th>
<th>Sagittal Location</th>
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<tbody>
<tr>
<td>&lt;25%</td>
<td>Extrusion</td>
<td>Central</td>
<td>Discal</td>
</tr>
<tr>
<td></td>
<td>Focal protrusion</td>
<td>R/L central¹</td>
<td>Pedicular</td>
</tr>
<tr>
<td>25%–50%</td>
<td>Broad-based protrusion</td>
<td>R/L subarticular</td>
<td>Infrapedicular</td>
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<td></td>
<td></td>
<td>R/L foraminal</td>
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<td></td>
<td></td>
<td>R/L extraforaminal</td>
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Abbreviations: L, left; R, right.

Fig. 9. Disk protrusion and extrusion. Sagittal T2 (A), and axial T2 images at L3 (B), L4 (C) and L5 (D). Normal disk at L3, broad central protrusion at L4 and right central extrusion with caudal migration at L5. This suggests, but does not directly demonstrate, that there has been complete disruption of the L5 annulus.
provides reasonable contrast resolution and can identify root compressive lesions such as disk herniations in the vast majority of cases. Radiation dose must always be considered when using CT, particularly in younger patients, and in serial examinations. In the cervical spine, CT or CT myelography may add value in their ability to distinguish bony osteophyte from soft disk, which may alter the surgical approach. One by-product of the rapid recent technological advance of CT is that the literature contains no comparative studies between MR imaging and the current generation of multidetector CT scanners in the detection and characterization of disk herniations.

Thornbury and colleagues, in 1993, demonstrated little difference in the accuracy of MR imaging, CT Myelography, or CT alone in the assessment of herniated disk-related root compressive disease. In a review article by Jarvik and Deyo, the sensitivity of CT in the detection of lumbar disk herniation ranged from 62% to 90%; for MR imaging the sensitivity ranged from 60% to 100%. The specificity of CT ranged from 70% to 87% and for MR imaging from 47% to 97%. According to Janssen and colleagues, sensitivity and specificity are higher in MR imaging than in CT and CT-myelography. The investigators studied 60 patients who underwent surgery on 102 disk levels. The correlation between preoperative finding and surgical finding was much higher with MR imaging (96%) than CT (57%) and higher than CT-myelography (84%). A more recent study by van Rijn and colleagues found no evidence that CT was inferior to MR imaging in the detection of disk herniation. There was, however, more interobserver variability in detecting root compressive lesions with CT than MR imaging. This study used 2-slice CT scanners. There are no studies comparing current generation 64- to 256-slice CT with MR imaging.

CT-myelography is a minimally invasive modality that plays a problem-solving role in the lumbar region, and it is recommended for patients with contraindications to MR imaging, or in the postoperative spine in which metal artifacts may obscure critical anatomy on MR imaging. Intrathecal contrast media allows for accurate detection of root impingement and central lateral recess and foraminal stenosis. MR imaging has long been considered the best single diagnostic test for imaging the cervical, thoracic, and lumbar spine for disk herniation in patients with radicular pain syndromes, despite the modest evidence basis. The superior contrast resolution of MR imaging allows direct visualization of herniated disk material and its relationship to neural tissue, including intrathecal contents. With the use of gadolinium, there is an opportunity to display the inflammatory reaction critical to the pathophysiology of radicular pain or radiculopathy. There are no studies to assess the potential degree of specificity this may add. In the postoperative spine, enhanced imaging allows discrimination of scar from recurrent disk, which is discussed elsewhere in this issue.

**MR IMAGING: RELIABILITY**

Lurie and colleagues analyzed MR images of randomly selected patients with intervertebral disk herniations from the Spine Patient Outcome Research Trial (SPORT). They noted high ($\kappa = 0.81$) interobserver agreement for disk morphology when classified as normal/bulge, protrusion and extrusion/sequestration. There was only moderate interobserver agreement for thecal sac ($\kappa = 0.54$) and nerve root compression ($\kappa = 0.47$). Pfirrmann and colleagues proposed a grading system for nerve root compression. The investigators divided the relationship of the herniated disk and the nerve root into 4 categories: no compromise, contact with the nerve root, deviation of the nerve root, and compression of the nerve root. The interobserver reliability ($\kappa = 0.62–0.67$) and intraobserver reliability ($\kappa = 0.72–0.77$) were good. The correlation for higher grade of nerve root involvement (compression) was greater than for lower grade nerve root involvement.

Carrino and colleagues reviewed 111 MR imaging studies of patients between the ages of 18 and 87 to assess intraobserver and interobserver agreement for non-disk contour degenerative findings. They reported good interobserver agreement in rating disk degeneration ($\kappa = 0.66$) and moderate interobserver agreement in rating spondylolisthesis, Modic changes, facet arthrosis, and high-intensity zones ($\kappa$ ranging from 0.44 to 0.59). Intraobserver agreement was overall good for the same changes, with $\kappa$ values ranging from 0.66 to 0.74.

**DISK HERNIATION: SPECIFICITY**

The specificity challenges associated with imaging of the disk and disk herniations have been well known for decades. Age-related changes in the disk occur progressively throughout adult life without any relation to symptoms. Recent studies have addressed the prevalence of age-related disk findings (primarily T2 signal loss) in younger populations, primarily in Scandinavian countries; these are population-based studies of MR imaging regardless of symptoms. Kjaer and colleagues, studying children aged 13 years, found a 21% prevalence of disk “degeneration”. In a study of
adolescents, Salminen and colleagues found a 31% prevalence of disk “degeneration” in 15-year-olds, which increased to 42% in 18-year-olds. Takatalo and colleagues evaluated 558 young adults aged 20 to 22 years. Using the 5-point Pfirrmann classification of disk degeneration, they noted disk changes of grade III or higher in 47% of these young adults. There was a higher prevalence in men (54%) than in women (42%). Multilevel changes were identified in 17%. In a much earlier study of asymptomatic workers, Hult noted radiographic evidence of narrowing of disk space, osteophytes, and vacuum phenomena in 56% of those aged between 40 and 44 years, which increased to 95% in subjects aged between 50 and 59 years. These studies clearly identify these common findings in the disk as normal changes of aging or maturation.

The literature reveals similar results when the prevalence of disk herniations in normal subjects is examined. Hitselberger and Witten studied plain myelography of asymptomatic volunteers and noted that 31% of patients demonstrated disk herniations. A study of lumbar spine CT in asymptomatic volunteers by Wiesel and colleagues showed that in subjects older than 40 years, 20% had disk herniations. Similarly, Boden and colleagues evaluated MR images of the lumbar spine in asymptomatic volunteers; in patients older than 60 years, 36% had disk herniations, 79% exhibited annular bulges and 93% had disk “degeneration” or age-related change. Jarvik and colleagues noted that only extrusions, moderate to severe central canal stenosis, and direct visualization of neural compression were likely to be significant and would separate patients with pain from asymptomatic volunteers.

One of the consequences of this specificity challenge in the evaluation of disk herniations is that there will always be a background of asymptomatic disease on which may be superimposed changes causal of a current radiculopathy or radicular pain syndrome. Only a close concordance, a key in lock fit, of an imaging finding and an individual patient’s pain syndrome can suggest causation, which further implies that the imager must know the nature of a radicular pain syndrome if he/she is to suggest a causal lesion. Close communication between clinician and imager via the medical record, an intake document at the imaging site detailing the pain syndrome, or direct patient interview by the imager is necessary.

SENSITIVITY

The major sensitivity fault of spine imaging is discussed elsewhere in this issue. Both anterior and posterior column structures may change under axial load and physiologic positioning, especially extension. Disk herniations that do not appear to contact neural tissue in recumbent imaging studies may result in significant compression in the physiologic state. Zamani and colleagues noted an increase in disk bulging in 40% of disks showing age-related changes when imaged in an erect extended position. Weishaupt and colleagues observed that more instances of disk-neural contact were seen in images obtained in the seated position than those obtained in the supine position; there were also small increases in the frequency of neural deviation or compression, particularly in images generated in the seated extension position. Neural foraminal narrowing in the seated position was significantly associated with increased pain.

Willen and Danielson demonstrated that in 14% of patients with sciatica significant additional information was demonstrated on images obtained under extension and axial load, including accentuation of disk herniation, lateral recess or foraminal stenosis, distension of a synovial cyst, or reduction in dural sac cross-sectional area to stenotic dimensions.

IMAGING OBSERVATIONS IN DISK HERNIATIONS

MR imaging can beautifully demonstrate disk herniations and their effect on the thecal sac and nerve roots, particularly on T2-weighted images. Disk extrusions and sequestered fragments on T2-weighted images often show greater signal intensity than the parent disk; this may be a reflection of inflammation. Within the lateral recess or neural foramen, such T2 hyperintense fragments can be difficult to detect against the high-signal fat on fast-spin echo T2 images. Careful scrutiny of matched T1 images reveals the lesion, now hypointense against the bright intraforaminal fat. The greater spatial resolution of CT myelography may identify subtle lateral recess or foraminal lesions less well seen on MR imaging.

Ninety percent of lumbar disk herniations occur at the L4 or L5 interspace levels. The vector of disk displacement in most herniations is posterolateral, an interesting correlate with the higher proportion of incomplete annular lamellae in this quadrant. In the lumbar spine, the exiting nerve passes immediately inferior to the vertebral pedicle and exits the foramen above the interspace level. Therefore, most disk herniations do not affect the exiting nerve, but rather impinge on the traversing nerve, which exits under the next lower vertebral pedicle. For example,
a posterolateral L4-L5 disk herniation results in an L5 radicular pain syndrome or radiculopathy. For a lumbar disk herniation to affect the like-numbered nerve, it must be an extrusion with cephalad migration of disk material into the neural foramen. The imager must know the pain syndrome to assess the nerve root in question (Fig. 10).

**ROLE OF CONTRAST MEDIUM IN DISK HERNIATION**

Gadolinium enhancement is not usually used or required in examination of the unoperated spine. Unenhanced imaging can only detect the mechanical compression of a nerve, not the inflammatory response which is also necessary to provoke radicular pain. T2 hyperintensity on short tau

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**Fig. 10.** Disk herniations. (A) Sagittal T2-weighted image in a patient with left L5 radicular pain reveals a large extrusion with cranial and caudal migration of disk material. The extrusion severely narrows the thecal sac, but the patient had no signs of cauda equina syndrome only unilateral pain. (B) Axial T2-weighted image in the same patient at the L4 level. Note the compression of the thecal sac. (C) Axial CT image at the L4 interspace in a patient with acute left L4 radicular pain who is unable to tolerate MR imaging. Note the broad-based left-sided herniation. (D) Axial T2-weighted MR image in another patient with left L4 radicular pain. L4 disk extrusion with migration of extruded material into foramen displaces the nerve superiorly. (E) Axial T2-weighted MR image at L4 disk level well demonstrates the foraminal extrusion. (From Maus T. Imaging the back pain patient. Phys Med Rehabil Clin N Am 2010;21(4):725–66; with permission.)
inversion recovery or fat-saturated images may identify this reaction. If gadolinium is given, it will often be observed that the soft tissue seen on unenhanced images, thought to be herniated disk material, is largely enhancing inflammatory/granulation tissue about a small disk fragment (Fig. 11). When confronted by a patient with clinically evident radicular pain or radiculopathy and no evidence of a neural compressive lesion on standard imaging, it may be reasonable to consider an enhanced examination, which may reveal an inflammatory process associated with a disk whose annulus is incompetent, which is sometimes referred to as a chemical radiculitis, first described by Marshall and colleagues. The neural compressive component of the lesion may only be present on imaging with axial load and physiologic positioning.

The use of gadolinium in the postoperative spine is discussed elsewhere in this issue.

NATURAL HISTORY OF LUMBAR DISK HERNIATIONS

The natural history of disk herniation is spontaneous regression (Fig. 12). Moreover, there is a general agreement that extruded disks, large herniations, and sequestrations have a greater tendency to resolution when compared with small herniations and disk bulges. Maigne and colleagues followed up 48 patients with up to 48 months’ follow-up CT scans and observed that

Fig. 11. Enhancing inflammatory reaction surrounding sequestration. This patient presented with left leg pain. Axial T2 (A) and T1 (B) images at the level of the L5 pedicle demonstrate a sequestered disk fragment having migrated cephalad from the L5 disk. Fat-saturated enhanced T1 image (C) at the same level shows that the sequestered fragment is small, but surrounded by enhancing inflammatory tissue. Sagittal T2 (D), T1 (E) and fat-saturated enhanced T1 (F) images in another patient similarly show inflammatory enhancement about a caudally migrated L5 sequestration. Note also the enhancing Modic I change.
the largest herniations had the greatest tendency to decrease in size. Bush and colleagues confirmed these results in 165 patients with a 1-year follow-up CT. In this study, 76% of disk herniation and 26% of disk bulges showed partial or complete resolution. The large extrusion or sequestration has entered the highly vascular epidural space, initiating a significant inflammatory response as described previously. This inflammatory response is integral to the profound pain these patients feel but will ultimately resorb the extruded disk material. This is the basis of transforaminal epidural steroid administration in patients who have failed conservative therapy. If the inflammatory response can be attenuated and the patient is allowed to remain functional, natural history will bear out with resolution of the herniated disk material and the radicular pain syndrome over time. Annular bulges or contained protrusions have not breached the annulus to initiate a similar degree of inflammatory response; these herniations tend to be stable over time.

**CORRELATION OF DISK HERNIATION IMAGING WITH CLINICAL STATE**

The spine imaging correlates with axial discogenic pain are discussed in detail by Aprill and Maus.

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**Fig. 12.** Disk herniation resolution. This patient presented in 2006 with left S1 radicular pain because of a moderately large left central L5 disk extrusion. Sagittal T2 image (A) and axial T2 image at L5 (B). He was treated with a left S1 transforaminal epidural steroid injection with clinical resolution of pain. He presented 4 years later with new left L5 distribution pain. 2010 MR images (sagittal T2 image [C], and axial T2 image at L5 [D]) show that the L5 extrusion has completely resolved; a new L4 extrusion has developed.
elsewhere in this issue. The correlation of disk herniation imaging with the clinical presentation of radicular pain or radiculopathy has been well studied. The basic specificity fault is described previously. As noted in a systematic review by Chou and colleagues,54 there is no value in imaging patients at the initial presentation of back or limb pain. In another study not included in that review, Modic and colleagues55 examined 246 patients who presented with acute back pain or radiculopathy; all underwent MR imaging, but were randomized to either providing the imaging results to the patient and clinician or withholding them. A safety board did not intervene because there were no imaging findings requiring acute intervention in any patient. Patients were followed for 2 years and had a 6-week follow-up MR imaging. Sixty percent of patients had disk herniations at presentation, but there was no significant difference in the prevalence of herniations between back pain or radiculopathy patients. There was no relationship between herniation type, size, or change over time and patient outcome. Disk herniations characterized as extrusions showed a trend toward greater resolution. The presence of a herniation was a positive prognostic sign, as might be expected given its natural history. The investigators concluded that MR imaging does not have value in planning conservative care. They emphasized that a surgical decision should be based on clinical parameters, not imaging.56

This is reinforced by the study of Cribb and colleagues,56 who followed 15 patients with massive disk herniations who were not surgical candidates or declined surgery. All the herniations were extrusions or sequestrations occupying more than 66% of the spinal canal cross-sectional area. Fourteen of the 15 herniations diminished in size by more than 80% (area) in the 2-year follow-up period. One patient underwent discectomy for persistent pain despite significant decrease in size of the herniation. The one patient whose herniation did not decrease in size had complete symptom resolution; no patient developed cauda equina syndrome.56 In another study by Masui and colleagues, disk herniations were treated conservatively and followed for 7 years; 71% of herniations had diminished in size at 2 years, 95% at 7 years.57 Clinical outcomes were unrelated to the size of the herniation or age-related changes in the disk. A prospective observational study by Carragee and colleagues58 performed lumbar MR images on 200 asymptomatic subjects; over the next 5 years, a subset of these subjects presented for medical care because of significant back or leg pain, at which time another MR imaging was performed. Eighty-four percent of the subjects presenting with pain had either no change or regression of baseline changes. The only positive correlates were new root compressive lesions in 2 patients with radicular pain. There were no imaging predictors of functional disability; as has been well documented, psychosocial factors are the principle determinates of disability, not imaging. Providing value in imaging the patient with radicular pain demands knowledge of the clinical state to appropriately filter out the plethora of insignificant imaging findings; direct observation of nerve displacement or compression concordant with the pain pattern may help to plan subsequent intervention. The decision to undertake interventions should be clinical, not based on imaging features.

CERVICAL DISK HERNIATIONS

This article, and the issue as a whole, concentrates on the lumbar spine. It would remiss, however, not to illustrate similarities and contrasts in the imaging of patients with cervical or thoracic radicular pain.

The cervical intervertebral disks differ structurally from the lumbar disks. The cervical disks are thicker anteriorly than posteriorly and have a less well-defined nuclear/annular structure. There is no discrete annulus at the posterior disk margin. The cervical disks function less to disburse axial load. As in the lumbar region, age-related changes in the cervical spine are common, asymptomatic, and increase in prevalence with age. Matsumoto and colleagues59 studied nearly 500 asymptomatic patients using MR imaging and noted loss of T2 signal within cervical disks in 12% to 17% of patients in their 20s but in 86% to 89% of patients older than 60 years. Asymptomatic cervical cord compression was seen in 7.6% of patients, largely older than the age of 50. Similarly, Boden and colleagues38 studied 63 asymptomatic subjects using MR imaging and noted cervical disk “degeneration” in 25% of those younger than 40 years, and in excess of 60% of patients older than 40 years. Asymptomatic subjects older than 40 years had a 5% rate of disk herniations and a 20% rate of foraminal stenosis. Teresi and colleagues60 studied 100 asymptomatic subjects using MR imaging and noted asymptomatic cervical cord compression in 7% and either disk protrusion or annular bulge in 57% of subjects older than 64 years.

The natural history of cervical disk herniations parallels the lumbar region. Cervical disk herniations may undergo spontaneous regression, a finding that correlates with improvement in
a patient’s symptoms. Similar to the lumbar region, extrusions, migrated disk material, and laterally situated disk herniations are more likely to undergo spontaneous regression. As most lesions causing cervical radicular pain are not purely soft disk, but at least in part bony, overall regression of the root compressive lesion is less likely than in the lumbar region.

Cervical radiculopathy is a common clinical problem but less so than lumbar radicular pain or

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**Fig. 13.** Cervical disk herniation and foraminal compromise. Patient with prior C5-C6 fusion presents with right C7 radiculopathy. Sagittal T2 images (A, B) demonstrate C6 disk extrusion; note the extruded material is of higher T2 signal than disk of origin, a common observation. This is confirmed on axial fast-spin echo T2 (C) and gradient recalled echo T2 (D) images. In another patient with a right C6 radiculopathy, sagittal T2 image (E), and axial FSE T2 images (F, G) at the C5-C6 interspace suggest a disk–osteophyte complex and uncovertebral joint osteophytes compromise the C5-C6 foramen. The primary bony nature of the process is confirmed on CT images. (H, I) In the cervical spine, compressive lesions are more likely to be osseous than soft disk alone.
radiculopathy. In population-based data from Rochester, Minnesota, cervical radiculopathy had an annual incidence of 107.3 per 100,000 for men and 63.5 per 100,000 for women. The most common cause of cervical radiculopathy is a foraminal constriction of multifactorial origin including unco-vertebral joint hypertrophy, facet arthropathy, and loss of disk space height. Only 22% of cervical radiculopathies in this study were the result of herniated disk (Fig. 13). When herniations were present, the spinal nerves most commonly involved were C6 and C7. Generally the herniated disk is located posterolaterally, compromising the nerve root at the entrance to the neural foramen; occasionally the herniated disk is centrally located and causes myelopathy. Cervical nerves exit in the inferior aspect of the foramen; hence the exiting, not the traversing, nerve is most likely to be impacted by a disk herniation or a disk–osteophyte complex. The cervical nerves exit above the like-numbered pedicle; a C5 disk herniation compromising the C5-C6 neural foramen will impinge on the exiting C6 nerve.

The 2010 North American Spine Society evidence-based guidelines on cervical radiculopathy extensively reviewed the literature on imaging; the guideline recommendation is that MR imaging be performed as the initial imaging test, with CT myelography used in MR imaging-incompatible patients or when MR imaging is discordant from the clinical presentation. MR imaging approaches the diagnostic accuracy of CT myelography without invasion or ionizing radiation. CT myelography may be crucial when the nature of the compressive lesion, bone versus soft disk, may change an operative approach. The higher spatial resolution of CT myelography may reveal subtle lateral recess and foraminal lesions that are less conspicuous on MR imaging.

**THORACIC DISK HERNIATIONS**

Symptomatic thoracic disk herniations are uncommon; operation for symptomatic thoracic disk disease constitutes less than 1% to 2% of all disk surgeries. As in other segments, there is a high

Fig. 14. Thoracic disk extrusion in a 56-year-old woman with progressive thoracic myelopathy. (A) Sagittal T2-weighted MR image shows large T8 disk extrusion. Low T2 signal suggests calcification. Smaller T7 disk extrusion. (B) Only a thin rim of cord is seen dorsal to the extrusion on T2-weighted axial MR. Axial CT image (C) demonstrates coarse calcification in the disk extrusion. Note the linear sclerosis in the end plate, a finding often accompanying disk herniations. At surgery, the T8 disk perforated the dura; it was resected successfully. (From Maus TP. Imaging of the spine and nerve roots. Phys Med Rehabil Clin N Am 2002;13:487–544; with permission.)
rate of asymptomatic degenerative disk disease in the thoracic region. Wood and colleagues studied 90 asymptomatic patients using MR imaging. In this population, 73% of the patients had positive thoracic imaging findings, 37% had disk herniations, 53% demonstrated disk bulges, and 29% had asymptomatic cord deformity. In a follow-up study, the investigators reexamined a subgroup of their asymptomatic patients and showed that there was little demonstrable change over time in the size of asymptomatic disk herniations. There was a nonstatistically significant trend for small herniations to increase in size and for large herniations to diminish. New asymptomatic herniations appeared within the follow-up interval; no herniations became symptomatic.

The majority of symptomatic thoracic disk herniations occur in the mid thoracic and lower thoracic spine. In the surgical series of Levi and colleagues, T6 and T7 were the most common levels of operation. In the larger series of Stillerman and colleagues, (82 patients), the T8 through T11 levels most commonly required intervention. In this series, 76% of patients presented with pain, 61% with either motor or sensory dysfunction, and 24% with bladder dysfunction. Nearly two-thirds of the disk herniations showed evidence of calcification on CT imaging. At surgery, 7% showed intradural extension. Thoracic disk herniations at the level of the conus or high cauda equina can mimic lumbar radicular disease. Hence, the conus must be included in lumbar MR imaging.

Imaging of thoracic disk herniations is done using MR imaging or CT myelography (Fig. 14). As the central canal and vertebral bodies diminish in size in the thoracic region, spatial and contrast resolution become more critical. CT myelography has the greatest spatial resolution and may better demonstrate the presence of calcification within thoracic disks. MR imaging is noninvasive and can detect signal abnormality within the cord, which may serve as a marker of cord edema or venous hypertension, verifying the physiologic significance of a disk herniation. All imaging evaluation for thoracic disk disease must include careful enumeration of the segmental level involved. If a lesion that may require surgical or percutaneous intervention is detected, the imaging study should be extended to include sagittal images from the sacrum to the skull base. Communication between radiologist and surgeon or spine interventionalist is critical to avoid wrong segment interventions.

**SUMMARY**

Age-related changes in the disk are ubiquitous and unrelated to symptoms. Disk herniations may occur when there is degradation of the nuclear matrix and failure of the annulus. Radicular pain requires both an element of mechanical compression of neural tissue and an inflammatory response, likely mediated by TNF-α. Imaging of disk herniations suffers from the specificity fault seen in all spine imaging; disk herniations are frequently asymptomatic. The imager must know the nature of the pain syndrome to suggest a causal relationship with an imaging finding. The natural history of disk herniation is resolution. There is no relationship between the size, type, or change in disk herniations over time and patient outcomes. Patient disability due to disk herniation is primarily related to psychosocial factors not imaging. Selection of patients with radiculopathy or radicular pain for interventions, including surgery, must occur on clinical grounds, not based on imaging appearance.

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